Improvement of trapped magnetic flux density in melt-textured RE-Ba-Cu-O bulk superconductors

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博士学位論文内容要旨
Abstract

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論文題目 Title	Improvement of trapped magnetic flux density in melt-textured *RE-Ba-Cu-O* bulk superconductors 溶融凝固 *RE-Ba-Cu-O* バルク超電導体の捕捉磁束密度の増大		

The unique characteristic of zero resistance allows superconductors to carry large electrical current without energy dissipation, which is promising for the power applications. Meanwhile, the requirements from practical applications largely promote the R&D of superconducting materials, especially for the high temperature superconductor (HTS). $REBa_2Cu_3O_{7-\delta}$ (RE refers to rare earth elements) bulk HTSs have gained considerable attentions since they possess potential to trap high magnetic field working as cryomagnets. This research is focused on processing high quality bulk HTSs and improving the superconducting performance to meet the requirements of the practical applications.

RE-Ba-Cu-O HTSs have short coherence length and large anisotropy, thus any high-angle grain boundaries will act as weak links and seriously reduce the critical current density (J_c). We have explored the optimal growth condition for processing high textured RE-Ba-Cu-O single grains/domains. The raw material composition, heat treatment profile, seeding technologies and annealing conditions have been modified according to the crystal growth mechanism. Based on these works, a batch process of high quality Gd-Ba-Cu-O bulks has been realized by the cold seeding melt-growth technology employing Nd-Ba-Cu-O/MgO thin films as seed crystals. Meanwhile, we have also developed a novel seeding technology by combining a piece of MgO crystal and a buffer layer. The problems of the lattice mismatch and low reactivity between the MgO and RE-Ba-Cu-O matrix have been overcome by adjusting the chemical composition and the heat treatment condition of the buffer layer. It breaks the limitation of the maximum temperature for the cold seeding technology which depends on the melting point of the seed crystals.

Efforts have been made to modify the disadvantages in the micro-morphology of RE-Ba-Cu-O bulks processed by the top seeded melt-growth (TSMG): the pores due to the leakage of oxygen during growth; the cracks originated from the tetragonal/orthorhombic phase transition and the oxygen diffusion during annealing procedure; and the non-uniform distribution of RE_2BaCuO_5 (RE211) particles leading to growth accidents and formation of sub-grain boundaries. It has been found that supplying more liquid source during melt-textured growth is beneficial for homogenous distribution of RE211 particles in the matrix. The hint was come from the infiltration and growth technology. As a modified TSMG technology, additional liquid source has been provided during the growth of Gd-Ba-Cu-O bulk samples. The liquid source rich environment leads to a sufficient growth at the *a*,*b*-plain with a increased growth rate. More importantly, the additional liquid source inhibits the accumulation of Gd211 particles at the growth front, thus reduces the growth accidents and the formation of sub-grain boundaries. Thanks to these, the trapped magnetic field of the Gd-Ba-Cu-O grains is largely enhanced.

It has been found that the additional liquid source also intensifies the Gd-Ba substitution. We attribute it to an increased concentration of the Gd ions in the liquid. As a macro represent of the second peak effect in the J_c-B curves, a peak of the trapped field has been found under the applied field. The flux creep date indicates that the magnetic field induced pinning sites exhibit larger pinning potential. The J_c-T relationship has been deduced from the J_c-B curves measured under different temperatures. The fitting curves are well consistent with the point-like pinning behavior. Assuming the field induced pinning sites are originated from the Gd-Ba substitution, the point like-pinning effect is reasonable since the disorders caused by the substitution are localized in a small scale, comparable to superconducting coherent length ξ.

The trapped magnetic field is proportional to both the diameter of the RE-Ba-Cu-O single grain and the critical current density. Chemical doping, introducing artificial pinning sites into the matrix has been considered. Both the Δl pinning contributing to the enhancement of self-field J_c, and the ΔT_c pinning improving the in-field J_c have been expected. Several doping candidates have been studied. It is found difficult to have the foreign particles embedded in the matrix homogenously without affecting the textured growth. The foreign particles, hardly being accepted by the matrix, would be pushed and accumulated at the growth front, which is prone to cause nucleation and growth failure. On the other hand, the ΔT_c pinning may be realized by chemical substitution. Both RE-Ba substitution and substitution at Cu sites are effective for improving the in-field flux pinning property, which is also known as the second peak effect in the J_c-B curves. To intensify the RE-Ba substitution, we have successfully prepared the Multi-RE, e.g., (Sm_xY_{1-x})-Ba-Cu-O single grains. In pursuit of new doping candidate, it was suggested to introduce magnetic particles into the matrix. We have tested several iron contained magnetic alloy particles and proved them to be effective for the second peak effect. The experiment results indicate that the enhancement of in-field pinning is originated from the substitution of the metal ions to the Cu sites. Furthermore, introducing disorder in both Cu-chain and Cu-plain is proved to be more effective.

After achieving the textured single grains, a magnetization procedure is required for practical applications. The results of the field-cooling and zero-field-cooling magnetization well agreed with the critical model (Bean model) indicating a homogenous flux pinning property of our bulk samples. In pursuit of the advantages of compactness and mobility, the pulse field magnetization (PFM) has been studied. Since a large pulse magnetic field is applied in a very short time, the heat generated by the flux penetration largely affects the flux creep. It is suggested that the real challenge is to remove the heat generated by the flux penetration before the flux creep, which makes the cooling efficient of the bulk a dominant factor for PFM process.